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DEVELOPMENT OF CANAL IN A PACKED LAYER

Abstract

The problem on the development of surface canal with increase of expenditure of flow is solved, the domains of physical parameters of problem responding to homogeneous pseudo-liquefaction and condition with the formation of open canal in a packed layer are determined.

One of the basic problems frequently originating on pseudo-liquefacted layer is formation of open canals in layer. Sufficiently small size initial canals are always present in dense layer of rigid particles in consequence of non-uniformity of packing. In pseudo-liquefacted layer we can consider such initial canals as some unavoidable fluctuations in random mutual disposition of particles. In this addition the question on the laws of development of long and narrow canals in dense and pseudo-liquefacted layers of rigid particles arises.

In paper [2] effective solution of hydrodynamic problem of flow in the given canal of finite length in packed layer of rigid particles is constructed and the sewing parameter is determined.

Now we consider the question on development of initial canal in packed layer. It's obvious that on the bottom of canal the greatest gradient of pressure is valid, therefore with increase of ϑ_0 the local zone of pseudo-liquefacted state, and also separation and wear of particles by flow of liquid arise first on the bottom of canal. Namely the local separation of particles from the bottom of canal is responsible for its development along its axis in packed layer of particles.

Later on we'll apply the general approach of collapse mechanics [5].

The force moving the canal is given by the next invariant of the Γ-integral [3,4,6]

$$\Gamma = \gamma \int_{\Sigma} \left(-\vartheta^2 n_z + 2\vartheta_n \vartheta_z \right) d\Sigma ,$$

$$\left(\gamma = \rho / 2\varepsilon^2 ,\ \vartheta^2 = \vartheta_r^2 + \vartheta_z^2 \right). \tag{1.1}$$

Here Σ is an arbitrary non-closed surface covering the bottom of cylindric cavity in packed layer, the contour of Σ coincides with some closed curve on the cylinder $r = r_0$, n_z is a constituent of the vector by unit external normal to Σ on the axis z.

We remined that the right hand side of the equality (1.1) is equal to zero for any closed surface of integration in packed layer. Using the invariance property, it's convenient to choose Σ that $\Sigma = \Sigma_0 + \Sigma_+ + \Sigma_-$, where Σ_0 is a lateral surface of a cylinder $r = r_*$, Σ_+ is an end-wall of a cylinder $z = -l - L$, Σ_- is an end wall of a cylinder with the hole $z = -l + L$, $r_0 < r < r_*$.

We choose the distance L as minimal so that one could ignore the influence of three-dimensional effects of flow near the bottom of the canal, not subjected to the description in frames of suggested approach. We remind that the bottom of canal corresponds to $z < -l$, $r < r_0$. The integral (1.1) by the surface Σ_0 is equal to zero, since $n_z = 0, \vartheta_r = 0$ on Σ_0. The integral (1.1) by the end-wall Σ_+ is equal to $-\pi \gamma r_n^2 \vartheta_0^2$, since $n_z = -1, \vartheta_n = -\vartheta_z = -\vartheta_0$ on Σ_+. For the calculation of the integral on the surface Σ_- (where $n_z = 1, \vartheta_n = \vartheta_z$) we use the condition $\vartheta_r >> \vartheta_z$ and formula [2].

We obtain

$$\gamma \int_{\Sigma_-} .... = \gamma \int_{\Sigma_-} \left(\vartheta_z^2 - \vartheta_r^2\right) d\Sigma = -2\pi\gamma \int_{r_0}^{r_*} \vartheta_r^2 r dr = -\pi\gamma \vartheta_0^2 r_0^4 (th\Delta l)^2 . \qquad (1.2)$$

We note simultaneously that within the limits of the exactness of the applied approach, the quantity of the integral (1.1) by lateral surface of the cylinder Σ_c (for $r = r_0$) will be equal to

$$\gamma \int_{\Sigma_c} .... = 4\pi r_0 \gamma \int_0^L \vartheta_r \vartheta_z dz = -2\gamma \int_0^L q \vartheta_z dz = \frac{16\gamma k_0}{4 r_0^4} \int_0^L q Q dz = 0 . \qquad (1.3)$$

Here the next formulas were used [2]

$$Q = -\frac{\pi r_0^4}{8\mu}\left(\frac{dp}{dz} + \rho g\right), \qquad (1.4)$$

$$p = P - \frac{\mu q}{2\pi k_0} \ln \frac{r}{r_*}, \qquad (1.5)$$

$$\vartheta_r = -\frac{q}{2\pi r}, \qquad (1.6)$$

$$\vartheta_z = -\frac{k_0}{\mu}\left(\frac{dp}{dz} + \rho g\right) - \frac{1}{2\pi}\frac{dq}{dz} \ln \frac{r}{r_0} . \qquad (1.7)$$

It gives the reason to suppose the quantity Γ in (1.1) as invariant with respect to the non-closed surface Σ.

As a result the integral (1.1) by total surface will be equal to

$$\Gamma = -\pi\gamma r_0^2 \vartheta_0^2 \left(\frac{1}{\lambda^2} + \frac{1}{8\delta} th^2 \Delta l\right),$$

$$\left(\Delta l = \frac{4}{\lambda}\sqrt{\frac{8}{\ln\left(\frac{1}{\lambda}\right)}}, \ \lambda = \frac{r_0}{l}, \ \delta = \frac{k}{r_0^2}\right). \qquad (1.8)$$

The formula (1.8) gives the value of driving force. According to the general theory the canal in packed layer doesn't develop, if $\Gamma < \Gamma_c$, where Γ_c is some physical constant of the present system for $\Gamma = \Gamma_c$ the movement of canal begins where by simple conception of limit state he equality $\Gamma = \Gamma_c$ is observed for all values of length of canal [2].

Later on we assume the conception of limiting state allowing most easily and clear analyze the development of canals in packed layer. According to this conception in the formula (1.8) we obtain the dependence of the length of the canal l on expenditure of liquid in the following form

$$\vartheta_0 = \left(\frac{1}{\lambda^2} + \frac{1}{8\delta} th^2 \Delta l\right)^{-1/2},$$

$$\left(\vartheta_0^2 = \pi\gamma r_0^2 \vartheta_0^2 / \Gamma_c\right). \qquad (1.9)$$

As it's obvious with increase of the length l of canal, corresponding equilibrium value of the expenditure ϑ_0 falls. It means that the development of canal from some initial value l_0, always happens unstable in non-stationary condition.

The quantities l_0 and r_0 play a role of some structure geometrical perturbation inherent in the present system. The critical quantity of the expenditure $\vartheta_0 = \vartheta_{**}$ at which the unstable channeling is begin is determined by the formula (1.9), when $\lambda = \frac{r_0}{l_0}$. For example, if we take for simplicity $\frac{l_0}{r_0} = m$, then with the help of (1.9) we find

$$\vartheta_{**} = \frac{1}{\sqrt{m^2 + \frac{1}{8\delta} th^2\left(4m\sqrt{\delta}\right)}}. \qquad (1.10)$$

Denote by $\vartheta_0 = \vartheta_*$ a critical quantity of expenditure at which homogeneous prseudo-liquefaction [5] begins. From stated it follows that the necessary condition of homogeneous pseudo-liquefaction is the following inequality

$$\vartheta_{**} \geq \vartheta_*. \qquad (1.11)$$

For $\vartheta_{**} < \vartheta_*$ the homogeneous pseudo-liquefaction isn't possible in consequence of origin of open canals in packed layer.

In conclusion we calculate the quantity Γ_c with the help of natural model of local pseudo-liquefaction, on the bottom of canal. And namely we'll assume that in limit-equilibrium state when the equality $\Gamma = \Gamma_c$ is valid on the whole bottom of canal for $z = -l, r < r_0$ the local pseudo-liquefaction holds i.e. the conditions for $z = -l$

$$r < r_0 \qquad \vartheta = \vartheta_n = \vartheta_z = \vartheta_* \qquad (1.12)$$

are satisfied.

Hence, using the invariance of Γ-integral and deforming the contour Σ in (1.1) to the circular area $z = l, \quad r < r_0$ we easily obtain

$$\Gamma_c = \pi\gamma r_0^2 \vartheta_*^2. \qquad (1.13)$$

Subject to (1.13) according to (1.9) we have

$$\overline{\vartheta}_0 = \vartheta_0 / \vartheta_* \qquad (1.14)$$

and the condition (1.11) on the basis of (1.9) will be as follows:

$$\frac{l_0^2}{r_0^2} + \frac{r_0^2}{8K_0} th^2\left(4\frac{l_0}{r_0}\sqrt{\frac{K_0}{r_0^2 \ln\left(\frac{l_0}{r_0}\right)}}\right) < 1. \qquad (1.15)$$

It's a necessary condition of homogeneous pseudo-liquefaction of packed layer. With the help of (1.10) we can construct a line on plane of the parameters $1/\lambda$ and $1/\delta$, separating the domains of homogeneous pseudo-liquefaction $(+)$ and canal formation in packed layer $(-)$.

Conclusion. Using the theory of invariant contour Γ-integral, the problem on development of surface canal with increase of expenditure is solved, the domains of physical parameters of problem responding to homogeneous *pseudo-liquefaction* and condition with the formation of open canal in packed layer are determined.

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TORSION OF VISCO-ELASTIC PRISMATIC PIVOTS IN GEOMETRIC AND PHYSICAL NON-LINEAR STATEMENT

Abstract

Geometrical non-linear torsion of physically non-linear visco-elastic prismatic pivot is stated in a general form. As a special case, the problem on the torsion of circular cross section of a solved is solved by successive approximations method.

Consider the torsion of a visco-elastic prismatic pivot by action of torque. We'll accept the coordinates of initial state. We choose origin of coordinates from one of the end-walls of pivot. We direct the axis Ox_3 along the axis of pivot. We introduce the following designations: R is length of pivot (L is assumed as sufficiently large), S is a lateral surface, S_1 is area of torsion.

Since we consider the problem in geometric and physical non-linear statement, then we calculate the components of the deformation tensor e_{ij} by the components of the displacement vector u_i by Green's formula

$$2e_{i,j} = u_{i,j} + u_{j,i} + u_i u_j . \tag{1}$$

We accept the physical relations between the components of stress tensor and deformation tensor in the form of [2]:

$$\frac{S_y}{2G_0} = э_y\left(1-\omega(\varepsilon_u)\right) - \int_0^t R(t-\tau)\left(1-\omega(\varepsilon_u)\right)э_{ij}(\tau)d\tau , \tag{2}$$

$$\frac{\tau}{K} = \theta . \tag{3}$$

Here $S_y = \sigma_{ij} - \sigma\delta_{ij}$ is a deviator of the stress tensor σ_{ij}; $э_{ij} = e_{ij} - e\delta_{ij}$ is a deviator of the deformation tensor e_{ij}, $\theta = e_{kk} = 3e$ is relative variation of volume; $\sigma = \sigma_{kk}/3$ is mean stress, G_0- is instantly-elastic shear modulus; K is modulus of deformation tensor. The kernel $R(t-\tau)$ characterizes rheological properties of material; $\varepsilon_{ij} = \left(\frac{2}{3}э_{ij}\cdot э_{ij}\right)^{1/2}$ is deformation intensity.

When $\omega(\varepsilon_u) = 0$ the equations (2) describe physical linear visco-elasticity characteristics.

We write an equilibrium differential equation and the boundary conditions [3]

$$\left[\sigma_{ij}\left(\delta_{ki} + u_{k,j}\right)\right]_{,j} = F_k ,$$

$$\left[\sigma_{ij}\left(\delta_{ki} + u_{k,i}\right)\right]l_j = R_{vk} .$$

We solve the problem in displacements. To this end we put the components of the stress (2) in equilibrium equations and boundary conditions and subject to relation between the components of deformation and displacements (1).

As a result we obtain

$$L_k(u) = F_k + F'_k + F_{\omega k} , \tag{4}$$

$$M_k(u) = R_{vk} + R'_{vk} + R_{v\omega k} . \tag{5}$$

Here the following designations are introduced.